A Comparison of Predicted Along-channel Eulerian Flows at Cross-Channel Transects from an EFDC-based Model to ADCP Data in South Puget Sound

Skip Albertson, J. A. Newton** and **N. Larson
Washington State Department of Ecology

Abstract
We compare the along-channel Eulerian flows computed from a model to data collected with a shipboard Acoustic Doppler Current Profiler (ADCP) at two transects in South Puget Sound near the Nisqually River. A comparison of this type is an important step in validating the model. The shipboard ADCP data were collected by running the boat normal to the main axis of the flow over a tidal cycle. Our data show that in regions where the mean exchange (residual) flow is large, it can be detected with only a 13-hour survey, at least during the time of the month where tidal inequalities between the lower-low and higher-low tides are minimal. Agreement of the ADCP data with the model on ebb and flood flow maxima is excellent. Agreement of the ADCP data with the model on residual flow is good, but the model shows a more even distribution of net export at the surface than the ADCP measured. This is a more stringent test and the disparity is perhaps due, in part, to the specific conditions of wind and climate forcing present during the time of data collection as opposed to error in the model itself.

Introduction
In order to understand the relationship between human activity, climate change, and Puget Sound, several three-dimensional estuarine modeling efforts are currently underway and are coordinated through a partnership of federal (US Navy), university (University of Washington), state (Washington Dept. of Ecology), local (King County Dept. of Natural Resources) and non-profit (Ocean Inquiry Project) institutions, funded through the National Oceanographic Partnership Program. Some of the most important quantities predicted by any model are the velocities and transports that will affect via advection any other variables, such as dissolved oxygen or pollutants, in water quality models.

We take predicted velocities from an Environmental Fluid Dynamics Code (EFDC, Hamrick 1992)-based model developed for South Puget Sound by Ecology (SPASM, http://www.ecy.wa.gov/programs/eap/spasm/index.html) and compare these to Acoustic Doppler Current Profiler data collected along select transects in Case Inlet and Drayton Passage. We compare barotropic ebb and flood tides to see how well the model duplicates cross-channel variability in along-channel flow. In addition, we average ebbs and floods from a synodic day (24 h 44 m) from both model and measured ADCP output to determine the baroclinic mean (residual) flow. The degree to which this can be done successfully in this region of high tidal exchange is a function of how much residual flow is present.

With the advent of modern Acoustic Doppler Current Profilers (ADCPs) we are now in a better position to validate models in coastal areas. We look at one such comparison of along-channel flow between ADCP data and the Ecology model (South Puget Sound Area Model or SPASM) of South Puget Sound at two specific locations (Figure 1), Case Inlet and Drayton Passage.

The length scale over which the Earth's rotation has a substantial effect on the flow, tending to turn it to the right in the northern hemisphere, is about 100 km (the barotropic Rossby radius). Since channel dimensions are much less than this in South Puget Sound, the flood tide would be expected to enter South Puget Sound as a plane wave with a uniform velocity front. This however, seldom occurs since the region is heavily stratified and this stratification is not simple increases of density with increasing depth. The lines of constant density are typically not parallel (Figure 2) indicating internal or baroclinic circulation, in response to density gradients. This internal flow is likely the combined result of forces like the wind, the channel geometry, and also Coriolis effects since the baroclinic Rossby radius is often less than 10 km. The channel geometry may have also been affected by the Earth's rotation during the period of its formation (indirect effect).

In addition to measuring the flow pattern over the complete tidal cycle and comparing it to a model, it is our intent to see how well the tidally-mean (residual) flow can be estimated with a minimal set of ebb/low/flood/high cross-channel transects at times of the month with symmetrical tides (Figure 3).

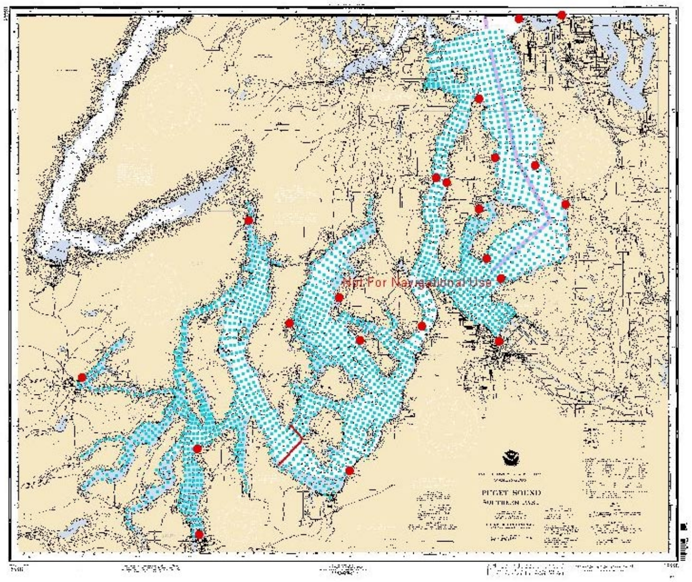

Figure 1. Locations of subject cross-channel transects (red lines), NOS tide gauge stations (red dots), and model grid cell centers (blue dots). The longer transect line is Case Inlet and the shorter line is Drayton Passage.

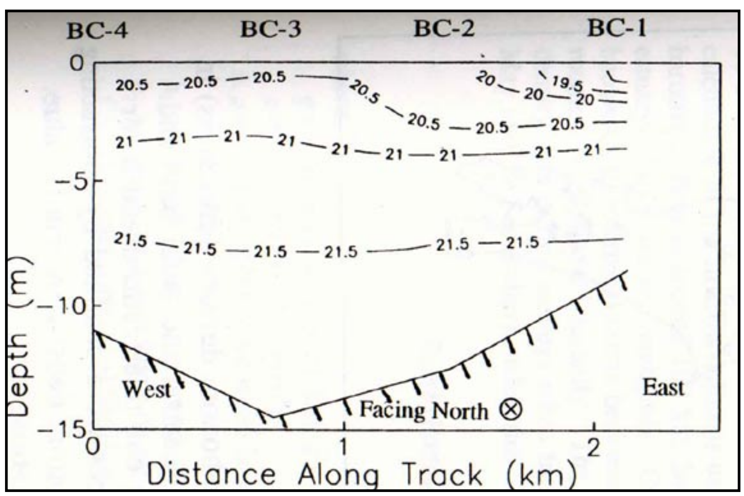

Figure 2. A hydrographic cross-section of density (sigma-t) near the south end of South Puget Sound at Budd Inlet.

Methods

We used a 300 kHz ADCP with four beams that each have a beam angle of 20 degrees to measure the fully vectorized flow along a transect that crosses each channel from shore to shore. We determined the along-channel flow by calculating the component of the total flow that is normal to the plane of our transect. With bottom tracking, pitch/roll, heading, and temperature corrections we were often able to get results to within one or two meters of the sea surface. We applied horizontal and vertical bin-averaging in MATLAB after Pawlowicz (http://www2.ocgy.ubc.ca/~rich/).

There are many possible velocity errors due to the misalignment of the ADCP on the boat mount. The most serious of these is the angle between beam three on the ADCP and the centerline of the boat (Figure 4). One method to remove this error in the estimation of the mean flow is to make an equal number of passes along the transects in opposite directions, thereby canceling it out. The minimalist approach we used in this study was to make an estimate of the error from the assumption that the mean of all the flow through the plane of the transect should sum to zero over the complete tidal cycle. If it did not, we subtracted this mean transport from the flow to obtain a corrected estimate of the residual. This forces the total flooding tide to balance with the total ebbing tide.

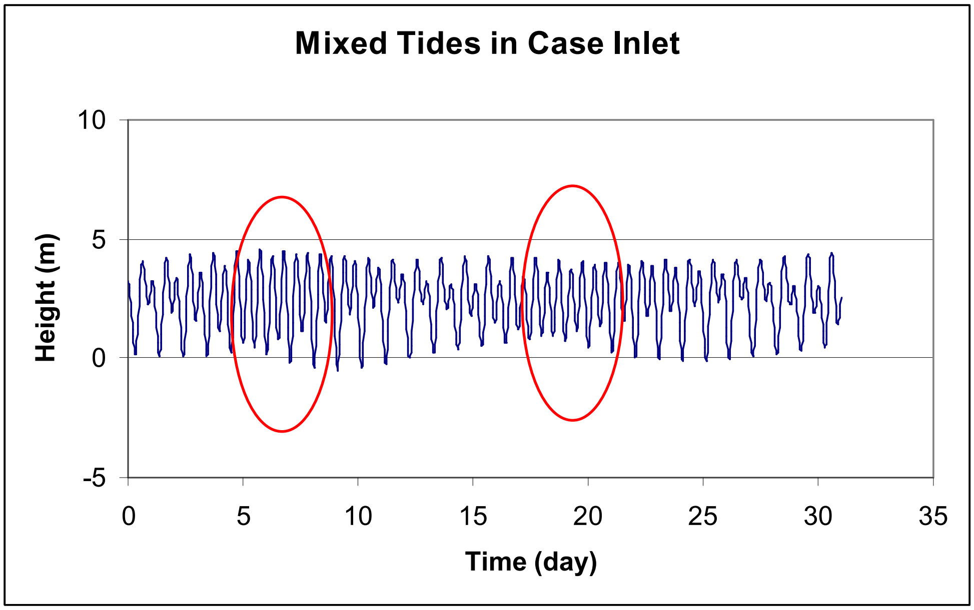

Figure 3. The predicted tidal response in Case Inlet with mixed tides for a month. The inequality of the tides (difference between higher and lower lows) is minimized (near symmetrical) twice during this period.

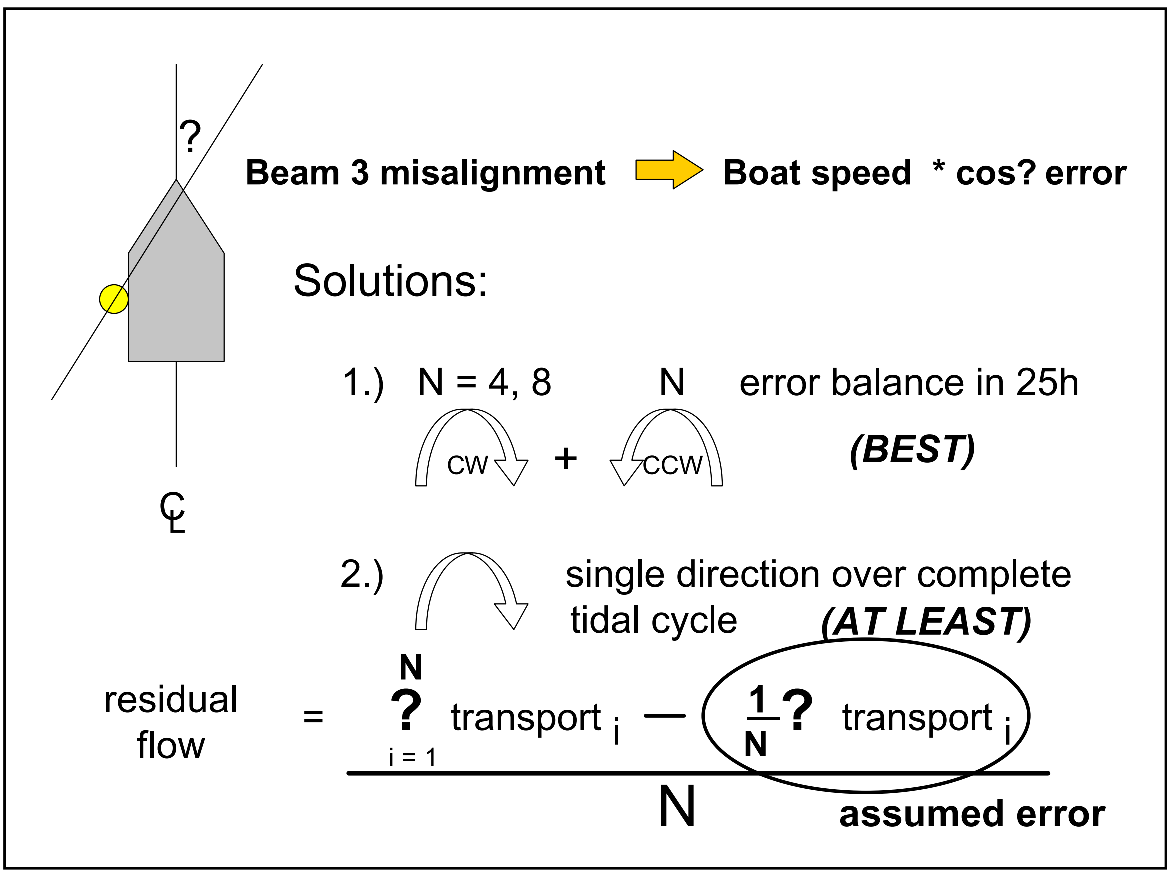

Figure 4. Two methods to remove the largest beam angle misalignment error. Method 1 balances equal numbers of transects taken in opposing directions. Method 2 assumes that all transport across the transect should sum to zero over the complete tidal cycle.

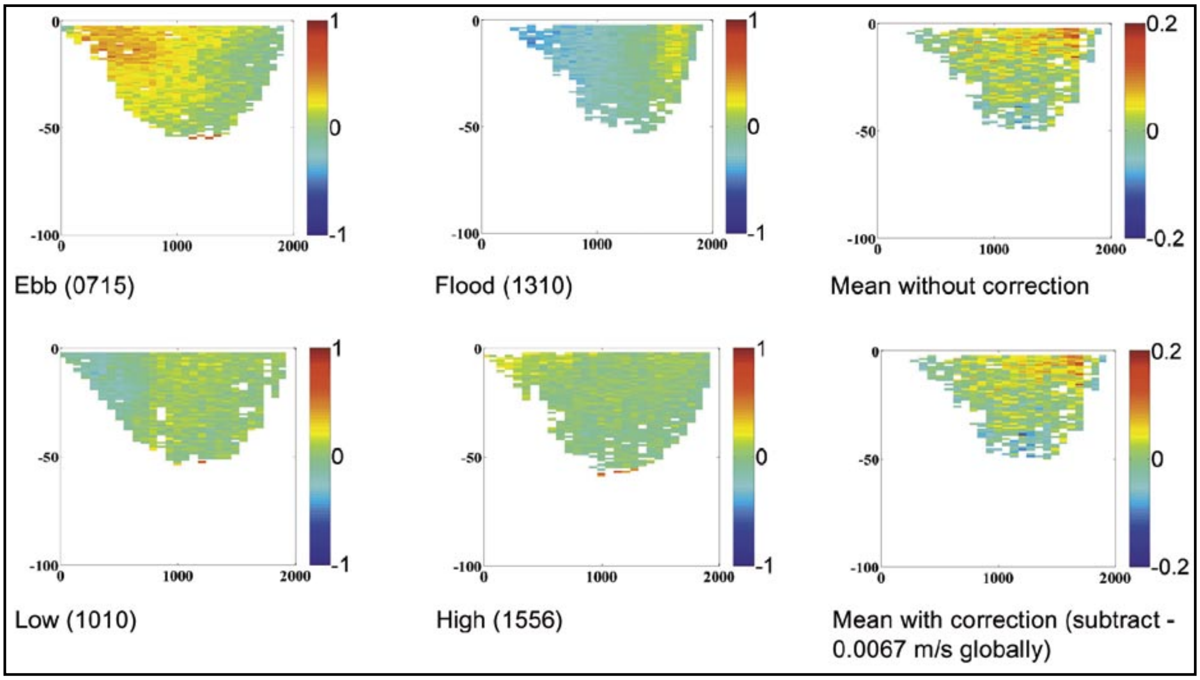

Figure 5. Flow normal to the plane of a north (left)-south (right) transect across Drayton Passage (see Figure 1) measured with an ADCP at ebb, low, flood, high, and resultant mean flow. X-axis is cross-channel distance in m, Y-axis is depth in m, and velocity color units are in m/s.

Results

The along-channel flows measured with an ADCP over a tidal cycle and the computed mean residual flows are shown for Drayton Passage (Figure 5) and Case Inlet (Figure 6).

Drayton Passage

The ADCP data from Drayton Passage indicate a progression in both ebb and flood tide from north to south across the channel entrance to Case Inlet (Figure 5). Using our technique to estimate the residual flow obtained results that are close to what would be expected: net flow out near the surface and net flow in on the bottom.

Case Inlet

The mean flows throughout South Puget Sound have been estimated with the SPASM and are shown with surface flow depicted in red and near-bottom flows in blue (Figure 7).

SPASM is presently configured to run only in the 1996-7 time period. Running the model for dates outside this period would require additional effort to create the input files of river flow and wind as well as boundary conditions. To compare our ADCP results from 4 October 2002 in the absence of such data, we thus used model estimations of the barotropic flood and ebbs from a tidally-equivalent SPASM day of 26 Sept 1996. These two days had equivalent tides and roughly equivalent wind and river inflow. The model has the advantage of being able to calculate a better estimate of the mean flow by using a 29d 13h period. The ADCP derived estimates of mean flow have the advantage of using real data but are averaged over only 13h. The comparison of these two methods is shown in Figure 6.

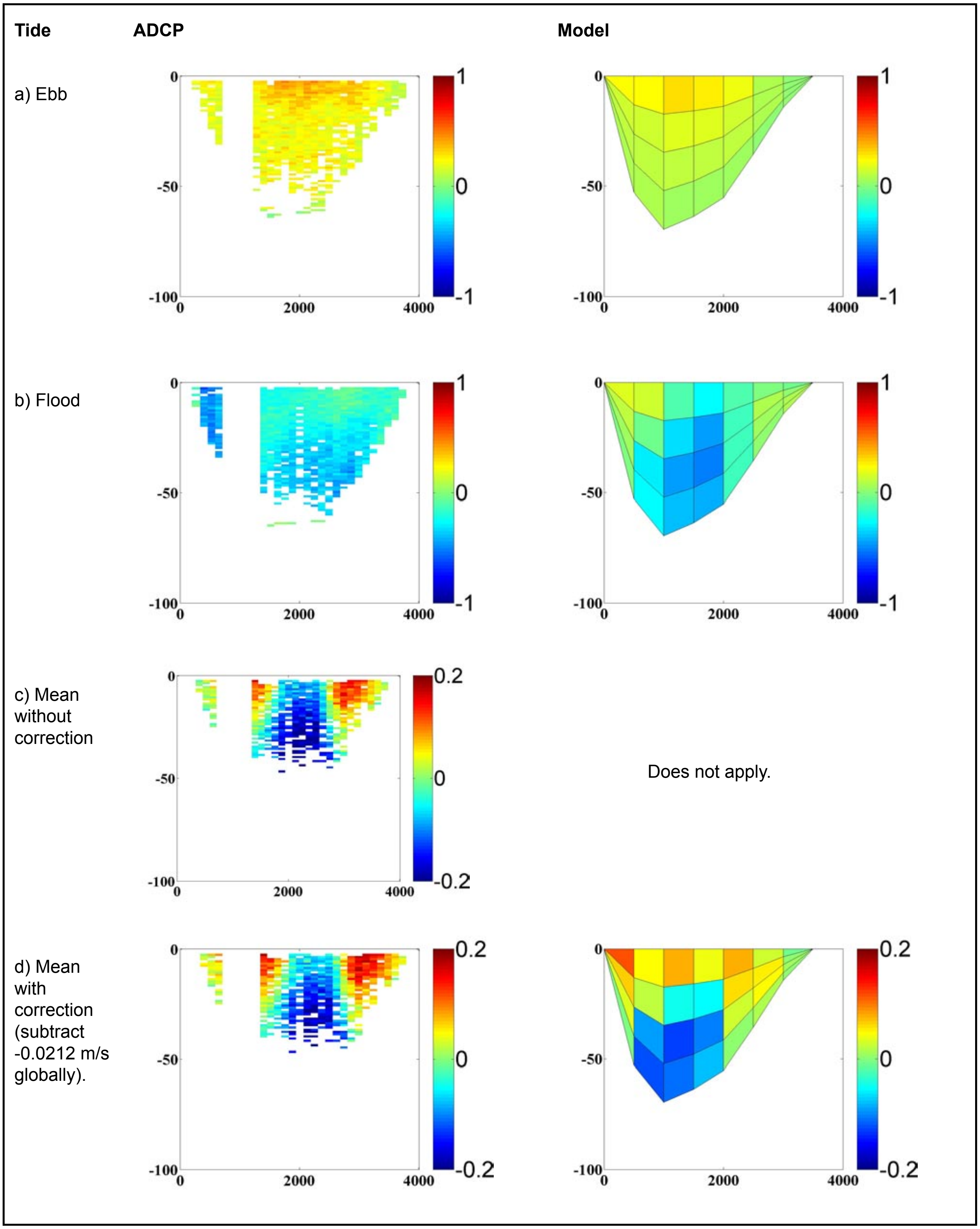

Figure 6. ADCP (4 October 2002) versus EFDC model (26 September 1997) along-channel flow comparison in South Case Inlet for a west (left)-east (right) transect (see Figure 1). X-axis is cross-channel distance in m, Y-axis is depth in m, and velocity color units are in m/s.

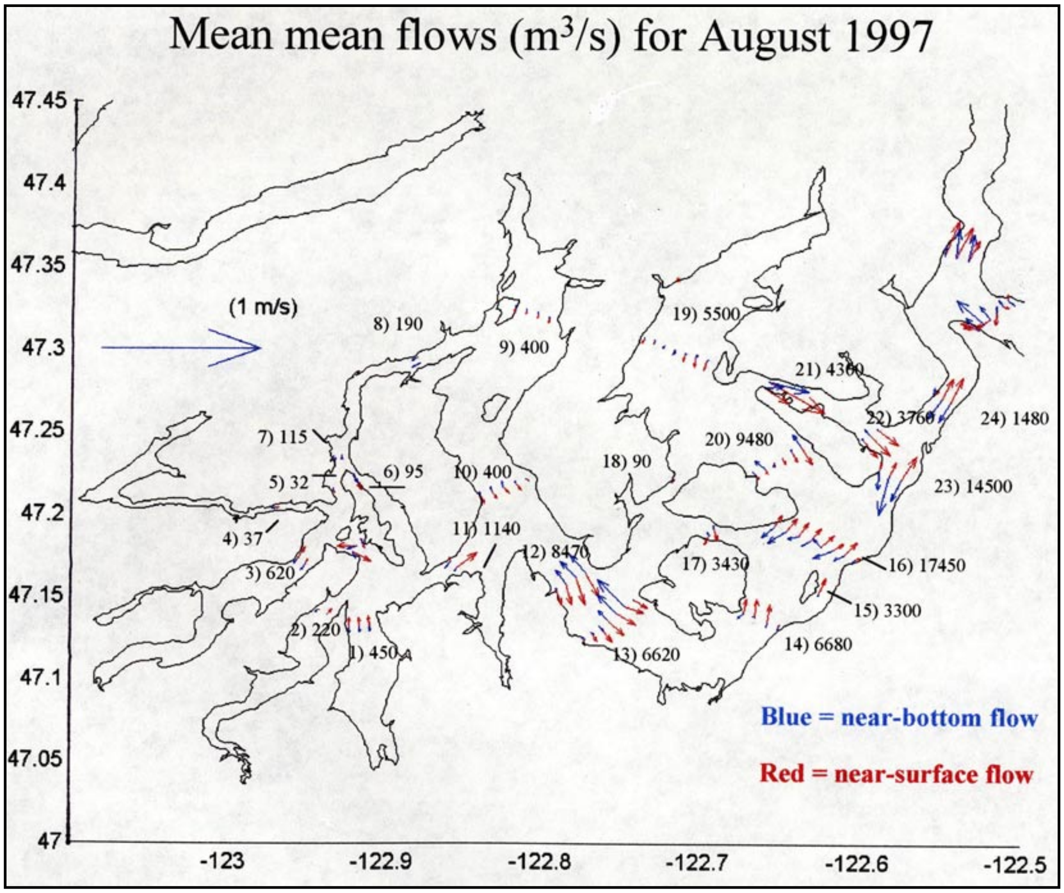

Figure 7. The mean of mean flows for August 1997 from SPASM at 24 locations throughout South Puget Sound where blue arrows are near-bottom flow and red arrows are near-surface flow. The Case Inlet transect is identical to transect 13) on this map. The mean inflow at center channel in this transect is larger than just to the north at transect 12).

Discussion

There is a good match of ADCP and model velocity and direction on ebbs and floods in Case Inlet (Figure 6a, b), which suggests confidence with model estimations of the mean flow. However, comparing mean flow is a more stringent test of model performance (Figure 6d). Both the model and ADCP residual flows are strongest in the center of the channel, but the model has outflow at the surface while the ADCP data has a mean outflow across all depths. Residual flow in the model looks similar to the ADCP but the difference may be due to the model's sensitivity to wind and river flows that were only approximately the same between the time periods we used. In addition, the transect we selected has a peculiar inflow (Figure 7; transect 13). The inflow in a similar transect just to the north (Figure 7; transect 12) has a more even inflow across the width of the channel.

Our method to estimate residual flow from ADCP data appears to work reasonably well where the mean exchange flow is significant compared to an ebb or flood tide. At our transect in Case Inlet the mean exchange flow is about 6,600 m^3/s and the peak barotropic flow at flood tide is 42,000 m^3/s.

Conclusions

Agreement in estimates of flow derived from ADCP measurements with the EFDC model for ebb and flood maxima is excellent. Agreement between the ADCP and model estimates of residual flow is good, but the model shows a more even distribution of net export at the surface than the ADCP measured. The discrepancy may be due in part, to the very specific conditions of wind and climate forcing present during the time of data collection as opposed to error in the model itself, though further investigation is warranted.

Acknowledgments

Funding for the field data collection was provided by grant N000140210498 from National Oceanographic Partnership Program (NOPP).

References

Hamrick, J. M., (1992). A Three-Dimensional Environmental Fluid Dynamics Computer Code, William and Mary, Virginia Institute of Marine Science, Special Report in Applied Marine Science and Ocean Engineering, no. 317.